DYNAMIC MODELLING OF A MULTISENSORIAL NANOMANIPULATOR

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ABSTRACT

This paper presents a dynamic system modelling approach of a nanomanipulator chain developed by the ICA-ACROE and LEPES laboratories. The chain is a very complex instrument, serving for precise sensing and manipulation in nanometer scale environment. The objective is to find a suitable model of the chain in view of stability and performances analysis, and for further control design of the feedback loops. Such a global model is here developed finding simulation schemes and also obtaining state space representation of the different parts of the chain (which are not presented in this paper). Experimental modelling and identification of the cantilever parameters are presented. The nano-scale tip-sample interaction forces are modelled too. Finally the simulation of the whole nanomanipulation chain is performed, simulating the approach-withdrawal operation which is in good accordance with the real patterns of experiments in physics.

1 INTRODUCTION

With the recent development of technologies for precise sensing and manipulation, the nanotechnologies became an emerging issue in many scientific fields like biology, physics, instrumentation etc. Today's nanotechnologies focus on sensing and manipulation capabilities in nano-space, which would in their applications allow us to act directly on living systems or physical structures with sofar unreached precision. This study is focusing on teleoperated nanoscale manipulation and sensing system, developed in the ICA-ACROE and LEPES laboratories, a tool that is allowing a human gestural interaction with a nanometer scale environment through a virtual environment. The objective of this paper was to describe and identify different parts of the nanomanipulator system developed by ICA-ACROE/LEPES laboratories and to find models of these parts. Such models will allow testing of the device under different conditions avoiding any damage on samples or the device itself. The analysis will help to solve stability and dynamics issues of the device.

A detailed block of the nanomanipulator diagram follows in fig. 1. The main parts of the chain are the following: Force Feedback Gestural Device (FFGD) serving for human control, Atomic Force Microscope (AFM) for sensing and manipulating in nano-scale environment, Real Time Workstation (RTWS) for the function described above. Yet another device is the Electronic Virtual Mass board, which was developed for interconnection purposes between AFM and RTWS. All specific parts of the chain will be studied in detail, presenting their functions and principles accompanied by models and. Simulations will be also performed.

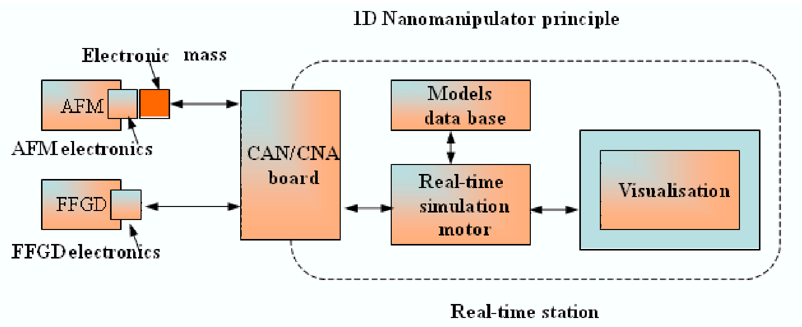

Figure 1: A more detailed block diagram of the nanomanipulator

2 ATOMIC FORCE MICROSCOPE

The Atomic Force Microscope (further AFM) works on the principle of scanning the environment with a probe with a sharp tip and therefore it is also often called a Scanning Probe Microscope. The AFM is designed for exploration and modification of object surfaces in nanometer scale.

Most AFMs utilize cantilever-type probes. The tip of the cantilever interacts with the nano-scale world and as forces are exerted on it, its lever bends and creates a deflection of the tip from the base position. This deflection is sensed by a photodetector system. Position of the probe is controlled by a piezo element attached to the base of the probe. The nanomanipulator uses the AFM in contact mode. Then the cantilever can be modelled as a simple mechanical oscillator - a system of a mass attached through a spring and a damper to the piezo drive. The model of the AFM will be further reduced to the model of the cantilever. There are three unknown parameters of such model: spring constant k_{can}, damping constant b_{can} and the mass m_{tip}. Please note that the mass of the tip just a modelled mass, it is not a real tip mass, because in the cantilever the mass is distributed through its length. These parameters were identified using various methods such as thermal noise excitation, Sarid's method [3] for spring constant identification with Gibson's cantilever approximation [1] etc.The identified parameters are following: $f_r = 24300Hz$,$k_{can} = 0.21Nm^{-1}$,$m_{tip} = 9.7147.10^{-12}kg$ and $b_{can} = 2.34.10^{-9}Nm^{-1}s$. The simulation scheme (block model) of the cantilever and the cantilever itself are shown in fig. 2. The model has been obtained using bond graph method. A corresponding state space representation was also found but will not be presented in this paper.

In order to complete the model of the AFM, surface-interaction model had to be created. In nanometer scale, surface and friction forces dominate the inertial forces, dynamics become faster etc. In order for this model to match the real systems, all dominant

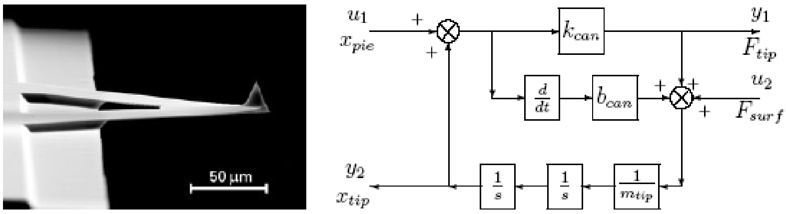

Figure 2: Cantilever type probe and its simulation scheme

forces - van der Vaals, capillary and electrostatic forces were modelled and included in the nanomanipulator chain, though these are due to insufficient space not presented in this paper.

3 ELECTRONIC VIRTUAL MASS

Electronic Virtual Mass board serves as a signal converter between the Atomic Force Microscope and the Real Time Workstation. Electronic Virtual Mass converts electric signals representing forces into a single electric signal representing position, its equivalent mechanical model is a mass that is attached to the ground by a spring and a damper. The input forces are exerted on this mass and the output signal is its position. The model of the Electronic Virtual Mass board, which was obtained from the electrical scheme, can be seen in fig. 3. Obtained state space representation is not presented.

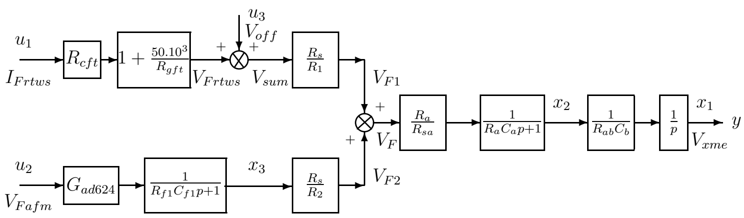

Figure 3: Detailed simulation scheme of the Electronic Virtual Mass

4 FORCE FEEDBACK GESTURAL DEVICE

In the nanomanipulator, the FFGD serves to the user as a controlling device, which has the capability of force feedback on his/her hand. Since the AFM is not a microscope in the classical meaning of the word, but it is in fact a force sensing device, force feedback haptic control is a very suitable option for the nanomanipulator from both control and perception point of view. The force feedback allow user precise mechanical sensing and also more accurate control. The only possible disadvantage - if the force actuated on the user limit him from manipulating - can be minimized in the appropriate setting of the model in RTWS.

The electrical/mechanical scheme of the FFGD and the user is shown in figure 4. The simulation scheme, obtained using bond graph modelling method, is also displayed in figure 4. C_{lvdt} is the constant of the position sensor. The parameters of the FFGD have been obtained from the schematics of the FFGD and from the creators of the device.

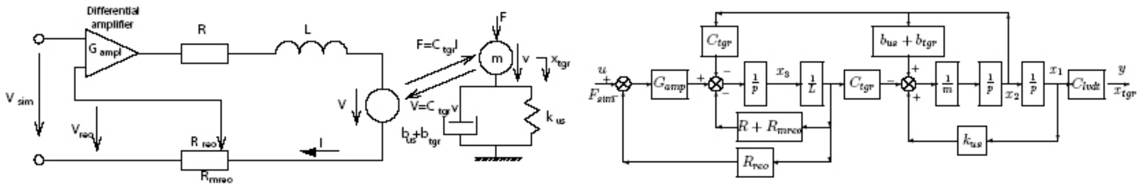

Figure 4: Mechanical/electrical scheme of the FFGD and the User and the simulation scheme

5 REAL TIME WORKSTATION

The Real Time Workstation (RTWS) serves as the interface between the two realities: the nanometer scale world of the cantilever and the macro environment of the human being. It creates a virtual environment, in which it processes the input signal from both realities and lets them interact in a way they can both perceive.

The RTWS is built on the Silicon Graphics Workstations platform, which has been modified in order to overcome the real-time computation constraints, especially the input/output section. The model which is currently being used for the nanomanipulator chain is a simple model of only two masses connected to each other by a spring. The two position inputs of the RTWS determine the position of these masses, while the force the spring exerts on each mass is taken as the output. Due to the simplicity of such model, we will not display it in this paper.

6 NANOMANIPULATOR CHAIN SIMULATIONS

The approach-withdrawal simulation using only cantilever and tip-surface interaction models is displayed in figure 5. We can see the position of the tip (x_{tip}) and the position of the cantilever drive - piezo (x_{pie}) while the piezo approaches and withdraws from the surface. The snap-on and snap-off of the cantilever tip is clearly visible, as well as the hysteresis - "sticking" - effect caused mainly by capillary forces. We also observe that electrostatic forces (voltage between the tip and the sample is $10V$) are causing a low deflection of x_{tip} from $x_p ie$ at quite long distances (such as 20 to 30nm).

In order to verify the behavior of the whole model, a simulation of the approach - withdrawal operation was performed. In this paper we will present withdrawal operation. The simulation results are displayed in figure 5. The variables x_{tip} and x_{pie} correspond to the positions of the cantilever tip and probe base (piezo element), F_{sim} is the force exerted on the user and the x_{me} and x_{user} are scaled positions of the user and the virtual - electronic mass. In the figure, we can see that the AFM forces are being exerted on the user during the withdrawal movement. The phenomenon of the "sticking" effect present in the nanoscale physics is simulated and the reaction of the chain model is examined.

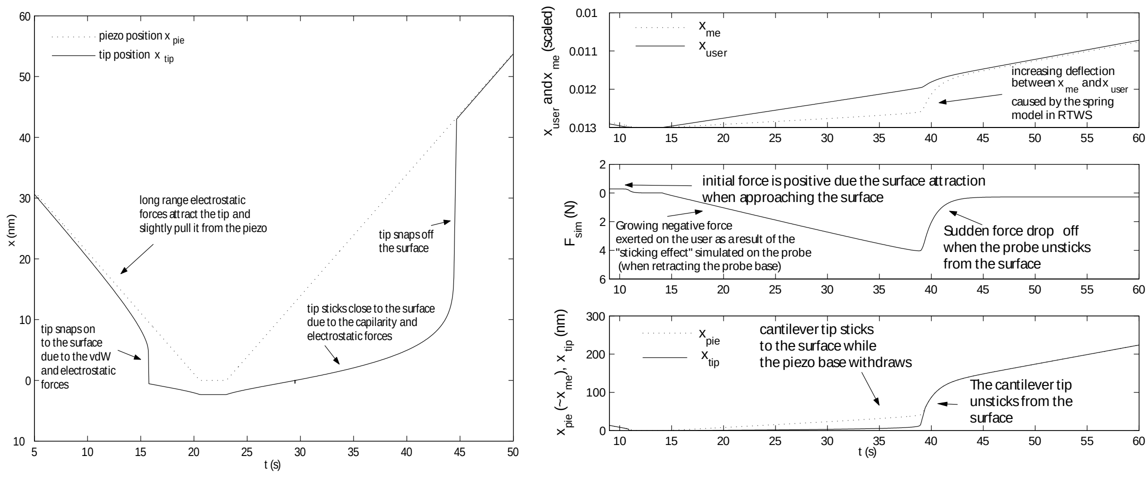

Figure 5: Approach-withdrawal simulation using AFM model and whole chain withdrawal simulation

7 CONCLUSION

The paper presented and explained the functioning of the nanomanipulator chain developed by ICA-ACROE and LEPES laboratories and also presented models of the devices in the chain. The models were used for modelling of a basic phenomenon appearing in manipulation in nanometer scale: the hysteresis - ”sticking“ - effect of the atomic forces actuation during the approach-withdrawal operation of the nanomanipulator’s probe.

Currently, a PC control system with ethernet adapter allowing distant access and control via internet is being developed. Such extension of the manipulator will allow the existence of global scientific projects with flexible real-time distant experimenting, profiting from the scientific potential of many people all over the world.

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